

# RADIO PHYSICS OF THE SUN AT DECAMETER WAVELENGTHS

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## Abstract

Radioastronomical study of the solar corona and radio emission of the Sun at decameter wavelengths (12–30m) have been carried out at the largest decameter UTR-2 radio telescope since 1972. The direction of this study are thermal and sporadic radio emission of the Sun and scattering of the radiation by the solar corona. The equipment for the observation of the Sun and the principal results obtained with it, in particular the two-dimensional brightness distributions of the quiet Sun and observations of the new type of sporadic solar radio emission (the diffuse stria bursts) are discussed.

The main goal of the theoretical investigations carried out in the Institute is the determination of the different properties of the radio emission of the Sun. The particular interest of this study is the construction of physical models of solar Type III bursts. The drift rate, the observed time profile, the brightness temperature of F- and H-components and so on are explained in the framework of these models.

## 1 Introduction

For study the solar wind and solar corona heating it is necessary to have parameters of solar plasma at height  $\geq 0.5R_{\odot}$ . Decameter wavelength range is supposed to be more perspective for this purpose. New interesting results have been obtained when large antenna systems with high resolution and sensitivity have been built. For investigating the solar corona and radio emission of the Sun a receiver complex has been developed on the basis of Khar'kov UTR-2 and URAN-1. The experimental complex consists of several blocks:

1. There is an eight-channel spectrograph of parallel survey in the range from 7.5 to 31 MHz. Its sensitivity is about  $10^{-21} \text{ Wm}^{-2}\text{Hz}^{-1}$  at 25 MHz; dynamic intensity range is about 40 dB; spectral and time resolution are 5 kHz and 0.1 s, respectively.

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2. There is a three-channel dynamic spectrograph of series-parallel survey as well. Frequencies of channels can be chosen in every transparency window of UTR-2. Spectrograph sensitivity is  $10^{-21} \text{ Wm}^{-2}\text{Hz}^{-1}$ , bandwidth is 10 kHz and constant time is 0.01 s. A signal is printed along an individual line during 0.25s and drawing velocity is  $1 \text{ mm s}^{-1}$ .
3. There is a three-channel (25, 20 and 16.7 MHz) two-dimensional radioheliograph for measuring angular size of the solar bursts and for getting two-dimensional radio images of elementary parts (each 25 arcmin in diameter) of the investigated sky and within the heliograph field of view about  $3.5^\circ \text{ (E-W)} \times 2^\circ \text{ (N-S)}$ . Heliograph sensitivity is about  $10^{-21} \text{ Wm}^{-2}\text{Hz}^{-1}$ .
4. There is a polarimeter with an original scheme of waves with circular polarization discrimination for measuring polarization degree of decameter solar bursts.

Scattering properties of the solar corona in the range from  $5 R_\odot$  to  $25 R_\odot$ , thermal emission of the quiet Sun, as well as local sources of Slowly Varying Component (SVC) of the solar radio emission and sporadic decameter radio emission of the Sun are investigated with this complex.

The principal results can be formulated as follows:

1. Extended radio sources occultation by the corona was observed [Bazelyan et al., 1970]. For the first time two-dimensional images of these sources were obtained. The angular width of the observed power spectrum at  $\lambda > 10 \text{ m}$  increases with  $\lambda$  somewhat less rapidly than  $\lambda^2$ . This fact can be explained in a non-uniformity solar corona [Bazelyan et al., 1970; Bazelyan and Sinitsin, 1971].
2. Two-dimensional brightness distributions of the quiet Sun are observed within decameter wavelength for the first time. Variations of these distributions are shown to have solar origin [Abranin and Bazelyan, 1982].
3. Observations of the quiet Sun [Abranin et al., 1978] and extended radio sources better agree with a corona model in which radial prolonged structures exist.
4. Enhanced radio emission of the quiet Sun is usually observed for tens of minutes after intensive Type III bursts. In our opinion this is an effect of isotropization of one-dimensional Langmuir waves generated by electron streams [Bazelyan, 1987; Bazelyan and Mel'nik, 1990].
5. In spite of reports of some workers there is no convincing evidence for the existence of local SVC sources at decameter wavelengths [Bazelyan, 1987].
6. Observations of Type IIIb-III bursts at 25, 12.5 and 6.25 MHz support fundamental-harmonic burst pairs interpretation [Abranin, 1986].
7. Observations of solar storms of Type III bursts show that
  - (a) when the emitting region is at the disc center F-harmonic takes place and

- (b) when this region is near the limb H-harmonic is realized [Abranin et al., 1980].
8. Deceleration of fast electron streams responsible for Type III bursts has been investigated within decameter wavelengths. This phenomenon is due to a collisionless mechanism [Bazelyan et al., 1977].
  9. Diffusive stria bursts and their chains III<sub>d</sub> have been searched for. After observations of stria burst positions it can be shown that they are superpositions of ordinary H-harmonic stria bursts and their echoes [Bazelyan et al., 1974].

## 2 Model of bursts by gas-dynamic theory

Type III bursts are the most intensive bursts at decameter wavelengths. In this paper we discuss a model of the bursts on the bases of gas-dynamic theory [Mel'nik, 1989] of spreading of fast electrons in a plasma. It is known that during their motion in a plasma fast electrons generate Langmuir waves, which interact also with these electrons. In this case an electron distribution  $f(v, x, t)$  and a plasmon spectral density  $W(k, x, t)$  can be described by the quasilinear equations

$$\begin{aligned}\frac{\partial f}{\partial t} + v \frac{\partial f}{\partial x} &= \frac{4\pi^2 e^2}{m^2} \frac{\partial W}{\partial v} \frac{\partial f}{\partial v}, \\ \frac{\partial W}{\partial t} &= \frac{\pi \omega_p}{m} v^2 W \frac{\partial f}{\partial v}.\end{aligned}\quad (2.1)$$

When the quasilinear relaxation time ( $\tau = [\omega_p \cdot n'/n]^{-1}$ ) is much less than the expansion time ( $t = x/v$ ):  $\tau \ll t$ , we can obtain the gas-dynamic equations

$$\begin{aligned}\frac{\partial}{\partial t} p u + \frac{1}{2} \frac{\partial}{\partial x} p u^2 &= 0, \\ \frac{1}{2} \frac{\partial}{\partial t} (1 + \beta) p u^2 + \frac{1}{3} \frac{\partial}{\partial x} p u^3 &= 0, \\ \frac{1}{3} \frac{\partial}{\partial t} (1 + \alpha) p u^3 + \frac{1}{4} \frac{\partial}{\partial x} p u^4 &= 0.\end{aligned}\quad (2.2)$$

Here  $p(x, t)$  is the plateau height of electron distribution;  $u(x, t)$  is the maximum electron velocity;  $\beta(x, t) = \int dk \frac{k}{\omega_p} W / \int dv m v f$ ,  $\alpha(x, t) = \int dk W / \int dv \frac{m v^2}{2} f$ . Taking into account the supplementary equation

$$\frac{\partial f}{\partial t} + v \frac{\partial f}{\partial x} = \frac{\omega_p}{m} \frac{\partial}{\partial v} \frac{1}{v^3} \frac{\partial W}{\partial t} \quad (2.3)$$

a self-similar solution of the gas-dynamic equation set (2.2) has been found as follows

$$\begin{aligned}p &= \frac{a}{t u |u - 2\xi|}, \quad \xi = x/t \\ a &= \text{const.}, \quad u = \text{const.}\end{aligned}$$

$$\begin{aligned}
W &= \frac{mav^4}{t\omega_p u} \left( \frac{1 - v/(2\xi)}{|u - 2\xi|} + \frac{v}{2\xi} \right), \\
\beta &= \frac{1}{3} \left( 5 - \frac{2u}{\xi} \right), \quad \alpha = \frac{1}{2} \left( 7 - \frac{3u}{\xi} \right), \quad \xi > \frac{u}{2} \\
\beta &= \frac{1}{3}, \quad \alpha = \frac{1}{2}, \quad \xi < \frac{u}{2}
\end{aligned} \tag{2.4}$$

This solution describes a beam–plasma structure of humplike form (‘plob’ [Russian abbreviation for ‘beam–plasma structure’]) (Figure 1) moving at a constant velocity  $v_{pl} = u/2$  (Figure 2). The fast electrons slow down in the region of  $\xi > u/2$  transferring part of their energy to plasmons, and they accelerate at  $\xi < u/2$  absorbing this energy. Both regimes correspond to 2 asymptotic self–similar solutions. There is a non–self–similar transition between them (see Figure 1) of width  $\delta\xi = (\tau u)/t$  determined by the quasilinear relaxation time. The situation is similar to that arising in gas–dynamics [Landau and Lifschits, 1986], when the front width of a shock wave is set by the particle free path length  $l_{fp}$ .

Using conservation laws for electron number and momentum and energy for system ‘electrons + plasmons’ we can find an instantaneous electron distribution  $f(v) = v\theta(u - v)$  at the time  $t = 0$  and at  $x = 0$  for solution (2.4). If the instantaneous electron distribution is different from  $f(v)$ , then the solution appears to be a sum of solutions (2.4) with some other  $p(x, t)$  and  $u(x, t)$ . The former has been evaluated for one–dimensional spreading of fast electrons. However, there are some processes which can break this approximation. The first process is scattering of fast electrons by the particles of plasma. But it is not effective because of  $1/\tau_{ee} \gg 1/t$  for these electrons. The second one is scattering of plasmons by thermal ions with changing of the wave vector  $\vec{k}$ . It can be shown [Mel’nik, 1991] that the effective pump of plasmons into a nonresonant region of phase velocities takes away a considerable part of the electrons and plasmons energy for  $v_{pl} > 0.3c$  and the plobs with these velocities cannot spread at large distance. Therefore a reason for an upper limit of plob velocity is scattering of plasmons by thermal ions. We suggest that Type III bursts consist of a lot of plobs, so the frequency drift of the bursts is limited by these processes also.

Plobs can generate electromagnetic waves at the fundamental plasma frequency ( $L + I \rightarrow T + I$ ) and at harmonic ones ( $L + L \rightarrow T$ ). Maximum brightness temperature at local plasma frequency  $\omega = \omega_p$  is

$$T_{Br} = 10^{12} \div 10^{13} \tag{2.5}$$

and at  $\omega = 2\omega_p$

$$T_{Br} = 10^{14} \div 10^{15} K \tag{2.6}$$

for  $n'/n = 10^{-6}$  and  $T = T_e = 2 \times 10^6 K$  [Mel’nik, 1991]. The brightness temperatures (2.5) and (2.6) quickly decrease with decreasing plob velocity  $v_{pl}$ . Radio emission of plob heaps is shown in Figure 3.

We took into account that all plobs erupted in the source on the Sun at the same time. Real Type III bursts have similar time profiles. We have calculated that  $\tau_{in} = 2s$  for increasing phase time and  $\tau_{de} = 5s$  for decreasing phase time at decameter wavelengths.

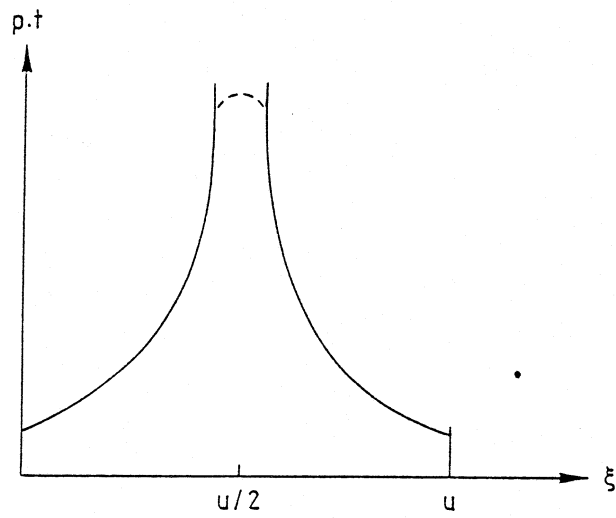


Figure 1: Beam-plasma structure of humplike form as a solution of Equation (2.4)

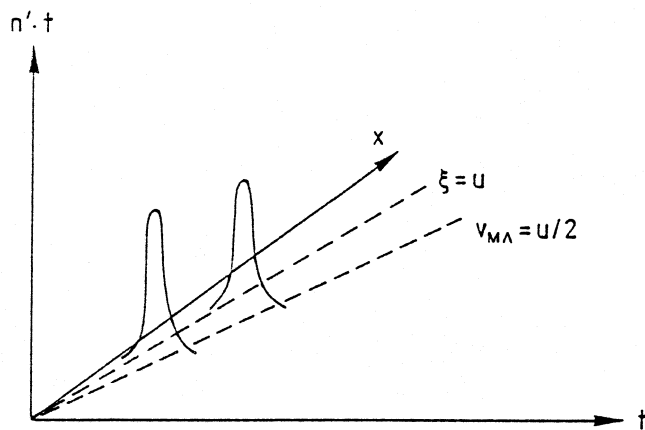


Figure 2: Beam-plasma structures moving at  $v_{pl} = u/2$

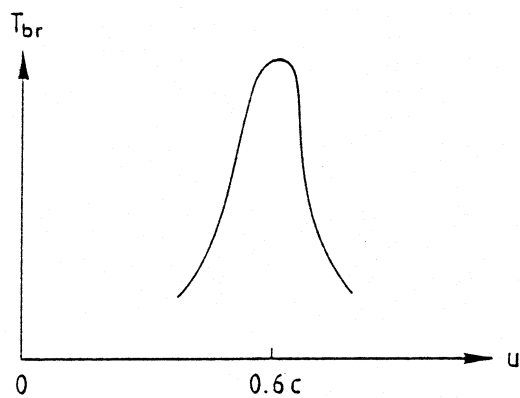


Figure 3: Radio emission of plob heaps

Taking into account a filling factor [Melrose and Dulk, 1988], phase volume in  $\vec{k}$ -space as well as beam of radiation we estimate the brightness temperatures of Type III bursts

$$T_{Br} = 10^9 \div 10^{11} K \quad (2.7)$$

in a gas-dynamic model. These temperatures are in good agreement with experimental data.

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